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Design of Metallurgical Production in the Context of Industry 4.0

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ABSTRACT
This article discusses a predictive quality management system that aims to eliminate repair technologies by exploiting the cognitive capability of manufacturing facilities in the manufacturing process. During production, deviations from the required quality parameters such as strip flatness, strip profile, and non-achievement of the required mechanical properties of dimensional variations occur, and their correction or correction requires repair technologies beyond the standard processes. The metallurgical process itself is energy and financially demanding. Repairing technologies represent added production costs and environmental burdens not only in the form of high-energy consumption but also in the production of harmful substances that have a negative impact on the environment. The production of solid dust impurities, the production of gaseous exhalations, high water consumption, environmental warming and water pollution, and the formation of slag ash are just a few negative aspects of metallurgical production. Steel producers make great efforts to achieve the required quality parameters and reduce the cost of repair technologies.

Keywords: Predictive quality management, rolling mill, repair technologies, pickling line

INTRODUCTION

This paper is focused on the predictive quality inspection system using Industry 4.0 tools at pickling line. Steel strip at the exit section of pickling lines is controlled following for next processing in case of the pickling operation is the final production operation these data are used for final inspection of pickled strip[1, 8]. That means inspection of surface imperfections, edge quality, strip flatness data out going from pickle line, position of weld, length, width, weight of coils. Very important are data from previous production processes such as data from steel shop and hot mill [11]. Each of these data predictively determine the best solutions for next processing and provide data for cognitive system mainly for pickling process and cold rolling process [3, 13].

Both in the past and at present, steel producing plants rate the quality parameters based on ex post at best in real time data or information. That data sets are usually rated by operators or computer systems – the make decisions and corrections regarding the further production steps. That means what is the proper processing of material/product that contain some defects. When defects already appeared on strip, it is already too late [2, 7]. Current quality inspection systems don´t allow predictive decision making. They are working with information in real time [6]. Therefore, the question is: What is predictive decision making? Predictive means something we know before it has happened. IoT system has certain information, it makes decision to minimize consequences to product and production process from previous operations, and at the same time, it rates data from next operations and conditions for choosing the best solution.

The environmental burden during production is one of the environmental burdens we call the primary environmental impact. The predictive production quality management system improves product quality not only during the production cycle but also throughout the product life cycle

[4]. This means the ability of the product to meet the requirements for its functionality and reduced service costs. Long product life significantly reduces the need to purchase a new product. Costs and energy consumption for recycling are also significant [5]. Costs and environmental burdens during the product use phase are called secondary environmental burdens.

METHODOLOGY

In predictive rating it is important to rate information coming with current substrate which include specifications of imperfections, for example the type of imperfection, location, size, repeatability and/or the distance of defects [14]. These data are rated between sending environment and receiving environment of production flow.

In case of deviation, predictive system is able to do a corrective action for elimination unintended consequences. As was mentioned above, very important are information coming with substrate where are described errors but equally important are data from predictive maintenance [9, 10]. Data from predictive maintenance include information about technical condition of production equipment as technical condition of the rolls, bearings, resonance of rolling stands, emulsion composition etc. Based on those data IoT system should suggest the right production process without loss of production efficiency. Data from predictive maintenance must be filled up with data from planned repairs [12]. These data are complementary for data obtained from level one sensors which are placed at production line and are evaluated by programmable logic controller (PLC). Level one sensors scan the position of production line parts, values of physical properties of parts as temperature, pressure, liquid flow etc. The measured values are compared with required values from Level 2, which determined process requirements for quality parameters assurance of product.

Problems detected during pickling process

Essential for pickling process are data incoming with hot strip. Coiling temperature basically determines difficulty level of process removing scales from pickled strip surface. Generally higher coiling temperature causes more difficult pickling process. During pickling process level one computer inserts steel grade by properties of the steel grade adjust parameters of pickling process such as speed of process, parameters of scale breaker, parameters of pickling solution etc. each of those parameters significantly influence pickling process. Camera inspection system controls the quality of surface and in case of under pickled surface it makes automatically corrective actions (decreasing speed of process part, increasing elongation at scale breakers) through the level one computer at the same time make cognitive actions. That means save data from causes to actions to results of parameters changes for quality. In the future during the same grade and same finishing temperature predictively use the same parameters. In Figure 1 is the screen from camera inspection system.

Symmetrical and asymmetrical flatness of hot strip significantly influence strip flow through pickling line. There are some critical ways. Looper: bad flatness may cause mistracking and subsequent damage of strip. In case of critical flatness level one computer based on incoming data predictively reduces the capacity of loopers and speed of required part of line for example entry, process or exit section. Lower capacity of loopers reduces probability of mistracking. When problematic part of strip passes through critical places of line main computer makes actions for increasing the productivity of pickling process.

In case of problematical mistracking of strip during going through loopers or another part of line computer compares maintenance data with coil flatness data. Based on the comparison smart line identifies source of problem, which should be at wrong flatness or wrong technical conditions of line. If smart system identifies deficiencies in the technical condition of line, it automatically sends exact information about problematic spare parts or problematical functionality of line part to maintenance department; in the future it might also directly order parts from a supplier of spare parts. If the system identifies the qualitative errors on the hot strip, smart pickling line sends data in to the hot mil smart control system and to quality process engineers who analyze incoming data and based on these analyses make corrective actions for eliminations of imperfections. Smart pickling line in Industry 4.0 works with data from predictive maintenance and uses data from finished maintenance. Simultaneously use data from sensors across line which give data about rolls, steering units, hydraulic cylinders etc. about a life cycle of these spare

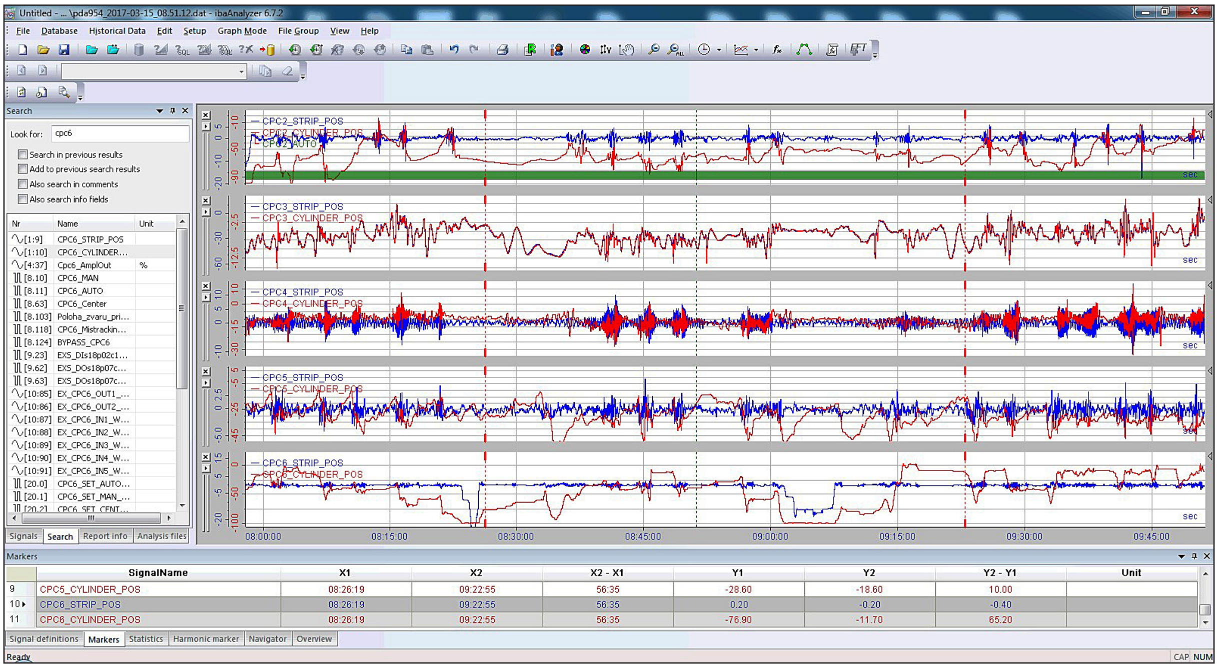

Figure 1. The form of data outputs from the scanned units of dominant importance for process quality control in ibaAnalyzer

parts. These data are evaluated and compared with processes at line. Figure 1 shows the form of data outputs from the scanned units of dominant importance for process quality control in ibaAnalyzer.

Side trimming process is more difficult when strip has edge waviness symmetrical or asymmetrical. Both cause problems during trimming process, so that L1 computer increases elongation at scale breaker this correction eliminates for minimum value of waves and simultaneously decreases problems with side trimming and loosing of steel tape at chopper. Figure 2 shows waviness samples – symmetrical and asymmetrical.

Flatness measuring results

Shape measuring device is laser measuring system usually used at hot mills contactless – due to high temperature of measured hot strip, contact measuring systems can´t be used – for example shape roll (stressometer). Flatness deviation at hot strip could manifest deviation or latent deviation. Disadvantage of shape measuring device is inability to measuring of latent flatness. Latent flatness is erased when strip is under very high tension so it seems like perfect flat shape and this condition shape measuring device is unable to measure realistic flatness. In this case flatness measuring at pickling line using a shape roll (stressometer) is important as it provides realistic data about strip flatness.

Scale breaker is multifunctional equipment that breaks scales on the surface of hot strip. This action improves removing process of scales, improves strip flatness and eliminates coil breaks. The strip flatness value is an important parameter that determines the quality of rolled products. Data about flatness incoming from hot mill to pickling line system and in to the cold rolling mill, these data are measured by the shape measuring device at hot strip mill.

In Figure 3 is a design scheme of smart IT architecture of flatness measuring at pickling line. At the beginning of this paper, we discussed predictive quality management system based on Industry 4.0 tools, which will make corrective actions for elimination of quality errors during the steel production process. Mainly was discussed hot rolling process, data from hot mill process which are coming with entering substrate in pickling line and predictively setup pickling and cold rolling process for achieving best production conditions and effectiveness. Data are obtained from:

- Camera inspection system.
- Shape measuring device.
- Sensors at hot mill.

During pickling process, hot data are analyzed simultaneously with data obtained from pickling process. L1 computer controls pickling process and set the best parameters. The L1 computer records process parameters and compares

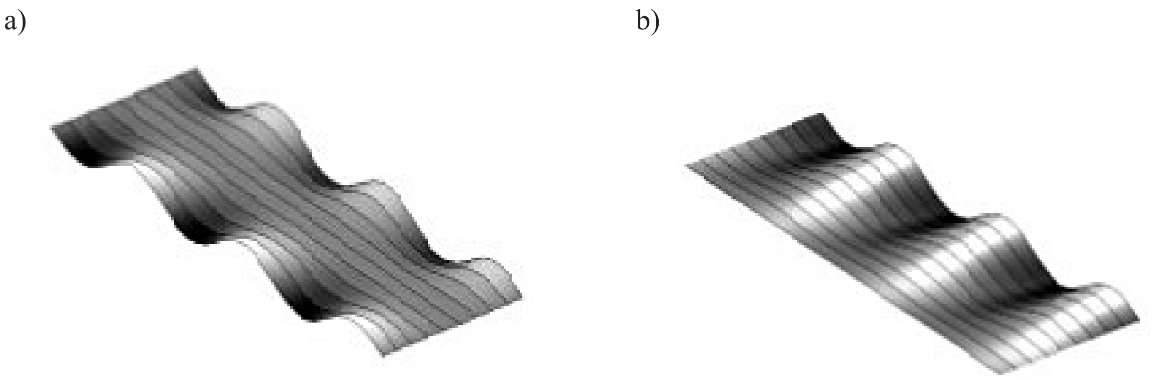

Figure 2. Waviness samples: a) symmetrical, b) asymmetrical

it with data recorded in past for strip with same properties this is the Cognitive ability. Cognitive system is able for increasing of process efficiency and elimination of process errors. Output data from pickling line are important for next processing of steel and are available via internet for next systems of production lines.

Quality control results

The individual's digital imperfection list serves to record deviations from the prescribed parameters in digital form. It is created in the moment of continuous slab casting at the continuous casting plant of the slab and accompanies the slab and later in production flow coil throughout the production flow until the moment of deliver. The individual's digital imperfection data list enters in to each production operation and transmits data to the production line control system. Based on the incoming data, the production equipment sets the process with respect to the desired parameters and with respect to any deviations from the required parameters of the incoming substrate with target to eliminate deviations during the process and to achieve the expected parameters. In the queue of incoming coils on the input track of the rolling mill, there are also data on imperfections that have incoming coils. The data is continuously evaluated and based on the signs of defects, the frequency of the quality controls of the rolled coils is calculated. In the process of calculating the frequency of quality controls, the correlation between:

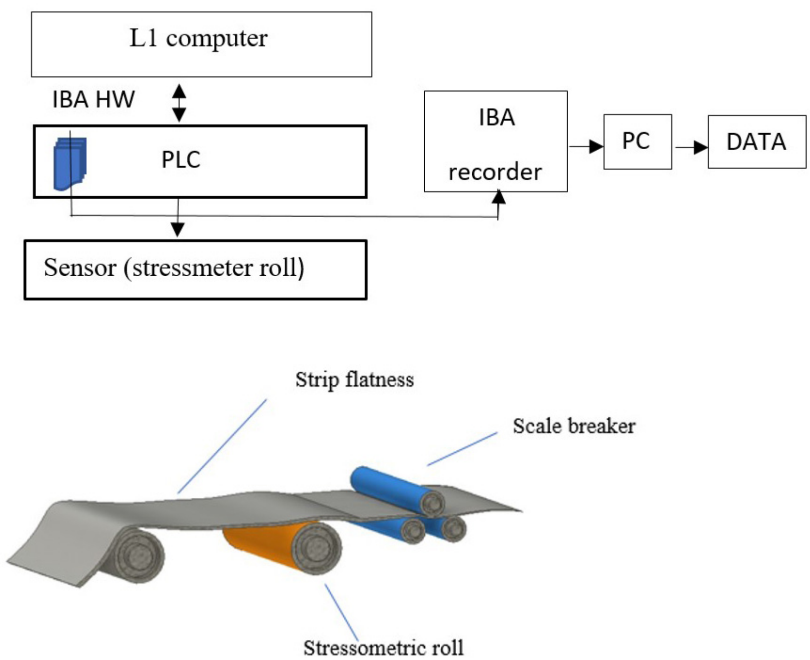

Figure 3. Design scheme of smart IT architecture of flatness measuring at pickling line

- Numbers of coils with quality imperfection.
- Severity of defects.
- Empirical coefficient.
- Unit of equation is number of quality controls on the number of rolled coils.

$$FQC = \frac{10}{(multiplicity + severity) \cdot empirical\ coefficient} \quad (1)$$

where: *FQC* – Frequency of quality controls,
multiplicity – the frequency of occurrence of defects per 10 coils entering the process,
severity – the severity of defects on the web surface,
empirical coefficient – experience from past.

In the case of a positive quality control result, rolling continues without correction intervention in the rolling process. The next quality control calculation follows from the rolling of the number of specified coils. In the case of a negative quality control result, the rolling mill operator will take corrective action to remove the cause of quality imperfection (roll replacement). Once the cause of quality imperfection is removed, a quality control is performed to verify the effectiveness of the correction process result. The calculation system simultaneously determines the number of rolled coils to the next control. The detected defect from quality control is recorded in a digital imperfection list. At the same time, two processes are in progress. The first is to hold the scrolls back to the previous quality control and secondary process SMART control system defines the most favorable direction of further processing in relation to the identified defect (Fig. 4).

Figure 4. Sample of surface defect

CONCLUSIONS

Increasing of product quality will significantly increase the life cycle of products made from steel strips in the form of higher corrosion, oxidation resistance and other negative effects. Due to the prolonged lifetime of product, the need for natural resources will be reduced, which will have a significant positive impact on environmental protection. The developed method is a way to reduce the necessity for additional production processes by using advanced technologies to eliminate the imperfections in the production process. The predictive system makes it possible to intervene in the production process in ordering to eliminate the shortcomings of the previous process. Further research is aimed at improving manufacturing technologies and implementing Industry 4.0 tools to eliminate the shortcomings in steel product manufacturing.

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